CATHODIC PROTECTION OF STEEL UNDER DIFFERENT ENVIRONMENT

LEE CHENG YIEW

Universiti Malaysia Sarawak
2002

Universiti Malaysia Sarawak
Kota Samarahan

fk

BORANG PENYERAHAN TESIS

Judul: **Cathodic Protection Of Steel Under Different Environment**

SESI PENGAJIAN: 1999 - 2002

Saya LEE CHENG YIEW
(HURUF BESAR)

mengaku membenarkan tesis ini disimpan di Pusat Khidmat Maklumat Akademik, Universiti Malaysia Sarawak dengan syarat-syarat kegunaan seperti berikut:

1. Hakmilik kertas projek adalah di bawah nama penulis melainkan penulisan sebagai projek bersama dan dibiayai oleh UNIMAS, hakmiliknya adalah kepunyaan UNIMAS.
2. Naskhah salinan di dalam bentuk kertas atau mikro hanya boleh dibuat dengan kebenaran bertulis daripada penulis.
3. Pusat Khidmat Maklumat Akademik, UNIMAS dibenarkan membuat salinan untuk pengajian mereka.
4. Kertas projek hanya boleh diterbitkan dengan kebenaran penulis. Bayaran royalti adalah mengikut kadar yang dipersetujui kelak.
5. * Saya ~~membenarkan~~/tidak membenarkan Perpustakaan membuat salinan kertas projek ini sebagai bahan pertukaran di antara institusi pengajian tinggi.
6. ** Sila tandakan (✓)

[ ]	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972).
[ ]	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan).
[✓]	TIDAK TERHAD	

Lee Cheng Yiew
(TANDATANGAN PENULIS)

Alamat tetap: LOT 453, RPR BATU KAWA,
JALAN BATU KAWA,
93250 KUCHING, SARAWAK

Tarikh: 15 APRIL 2002

Disahkan oleh

(TANDATANGAN PENYELIA)

DR. HA HOW UNG
(Nama Penyelia)

Tarikh: 16/4/02

CATATAN * **Potong yang tidak berkenaan.**
** **Jika Kertas Projek ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/ organisasi berkenaan dengan menyertakan sekali tempoh kertas projek. Ini perlu dikelaskan sebagai SULIT atau TERHAD.**

This project report entitled "**Cathodic Protection Of Steel Under Different Environment**" was prepared by Lee Cheng Yiew as a partial fulfillment for the Bachelor of Engineering (Hons.) Mechanical and Manufacturing System degree programme is hereby read and approved by:

Dr. Ha How Ung

(Project Supervisor)

Date: 16/4/02

Cathodic Protection Of Steel Under Different Environment

Lee Cheng Yiew

This report is submitted in partial fulfillment of the requirement for the degree of Bachelor of Engineering (Hons.) Mechanical and Manufacturing System from the Faculty of Engineering

Universiti Malaysia Sarawak

April 2002

ACKNOWLEDGEMENTS

The author would like to express his gratitude and appreciation to his Project Supervisor, Dr. Ha How Ung, for his sincere and undivided guidance, encouragement and advice throughout the duration of the project.

Furthermore, the author cannot adequately thank his family and friends for giving their support, help and useful tips during the drift and trying periods encountered during the research and report writing. Last but not least, not forgetting everyone who had involved in one way or another to the completion of the project, the author's deepest gratitude for them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTACT

Cathodic protection is deemed one of the most efficient corrosion prevention method and is widely used in the protection of pipe mains against corrosion around the world. Its ability of reduce corrosion to near zero had brought benefits either economically or human safety considerations. Cathodic protection consists of sacrificial anode and impressed current. This research explores the methods involved in designing an impressed current cathodic protection to protect steel from corroding in seawater and soil environments as well as to assess the effectiveness of cathodic protection in reducing the corrosion rate. Moreover, this project also investigates the theory and nature behind the corrosion of steel.

ABSTRAK

Perlindungan katod dianggap kaedah pencegahan pengkaratan yang paling effisien dan digunakan secara meluas untuk melindungi paip-paip utama terhadap pengkaratan di seluruh dunia. Kebolehan untuk mengurangkan pengkaratan sehingga hampir sifar telah membawa kebaikan bukan sahaja dari sudut ekonomi tetapi juga keselamatan manusia. Perlindungan katod terdiri daripada anod korbanan dan arus tekan. Kajian ini menerokai cara-cara dalam merekabentuk perlindungan katod jenis arus tekan untuk melindungi keluli daripada berkarat dalam persekitaran air laut dan tanah, serta menilai keberkesanan perlindungan katod untuk mengurangkan kadar pengkaratan. Selain itu, projek ini juga menyiasat teori dan sifat di sebalik pengkaratan keluli.

CHAPTER 1

INTRODUCTION

1.1 Overview

The word "corrosion" derives from the Latin, *rodere*, meaning "to gnaw", in the context of rats; and "corrodere" means "to gnaw to pieces". [Trethewey and Chamberlain] Corrosion is a major menace and continuous battle for engineer. As moisture and oxygen is ever present in the environment, corrosion will never cease. Corrosion just simply 'eats away' the metal, reducing the strength of metal to a substantial degree. The corrosion destruction of mechanical structures could inflict losses up to millions in repair work and servicing, not to mention the leakage and wastage of precious resources such as petroleum and treated water. Moreover, failure to observe corrosion could spell disaster and sometimes cause the loss of life when corrosion unleashes its destructive power. On 15 December 1967, Point Pleasant Bridge in Ohio collapsed, taking the life of 46 people. The cause of the catastrophe was later identified as stress corrosion crack 2.5 mm deep in the head end of an eye bar. The metal had a low resistance to fracture once a notch had been initiated and the minute crack would soon trigger the calamity. [Trethewey and Chamberlain] This is the reason why corrosion prevention is an important essence in engineering structure. Steel has been the heart of in many of today's modern architecture and machines equipment. It is the main engineering material used for ships, pipe and other

equipment, is mainly due to its strength and low cost. But steel is prone to corrosion if it is exposed to aqueous environments, soil or seawater and proper protection is not provided.

Since corrosion has such a destructive force, people had been deciphering the secrets of corrosion prevention. Many methods had been devised up. Cathodic protection is one of the ways to prevent steel or other metals from corroding. Since corrosion phenomena are electrochemical in nature; thus they can be nullified by electrochemical means. The use of cathodic protection had been proven its efficiency in various fields. According to Jones, it is the most widely used method of corrosion prevention and mitigation. Corrosion rate can be reduced to practically zero. For that reason, the metal can remain in a corrosive environment minus the corrosion deterioration. Now virtually all-modern pipelines are coated with an organic protective coating delivered by cathodic protection systems sized to prevent corrosion in the protective coating.

1.2 Background On Cathodic Protection

"Cathodic" is a derivative of the word "cathode" which means "the negatively charged electrode that receives cations during electrolysis". The definition of "anode" on the other hand is "the positive electrode toward which anions migrate in an electrolytic cell".

Cathodic protection was first developed by Sir Humphrey Davy in 1824 as a method to control corrosion on British naval ships. He presented a series of papers to the Royal Society in London, describing how zinc and iron anodes could be used to prevent the corrosion of copper sheathing on the wooden hulls of British naval vessels. It was applied to the frigate HMS *Samarang* and to be the first 'full-hull' installation on a vessel in 1824. The system worked so effective in corrosion prevention that the loss of copper ions required for toxicating the marine growth, that resulted in the marine fouling of the hull. Since then the interest in cathodic protection waned before it is used successfully by oil companies in United States to protect underground pipelines. [Shreir, Jarman, Burnstein]

The first application of cathodic protection by means of an impressed current was undertaken in England and the United States about 1910-1912. By then, the general used of cathodic protection had been widespread. [Schweitzer]

Explicitly, cathodic protection is an electrochemical means of corrosion control in which the oxidation reaction of a metal surface is suppressed from forming oxidation salts by supplying electrons to the metal to be protected (anode) and accelerate cathodic reaction. The basic concept of cathodic protection is that the electrical potential of the subject metal is reduced below its corrosion potential, and that it will then be incapable of going into solution, or corroding.

Cathodic protection can be achieved by two ways:

1. Sacrificial Anode
2. Impressed Current

1.3 Objective

The main objective of this project is to study the cathodic protection coatings of steel plate under different environment (seawater and soil). Furthermore, the purpose of the project also include:

- To design an impressed current cathodic protection for prevention of corrosion on steel plate.
- To study the nature of corrosion.
- To evaluate the effectiveness of cathodic protection as a way of corrosion control.

CHAPTER 2

LITERATURE REVIEW

2.1 Corrosion

2.1.1 Introduction To Corrosion

Corrosion is defined as destruction of material by chemical, electrochemical or metallurgical interaction between the environment and the material. Metals usually corrode due to oxidation with air to form oxides. The oxidized metal is porous and the strength of the metal is lost.

Corrosion is basically the universal law of nature in which the metals tends to revert to their natural states through corrosion due to a lower free energy associated with the forming of oxides. When steel is processed from iron oxide, energy is added to the steel. The amount of energy stored in the steel causes the material to be in an unstable state and thus when given the suitable environment, this energy will be released and the steel will be back to its natural state by the formation of oxide.

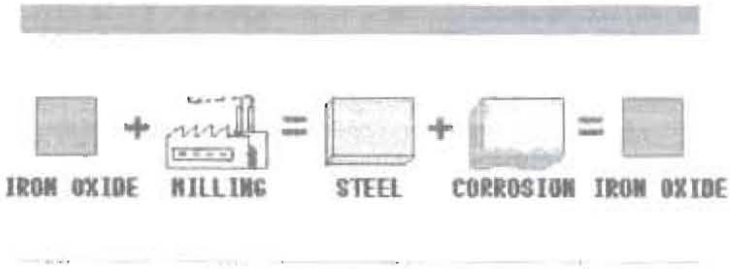

Figure 2.1: The law of nature from iron oxide to iron oxide

[http://www.cathodicprotection.com/cpintro.htm]

2.1.2 Types Of Corrosion

a) Uniform Corrosion

Uniform corrosion is a common form of corrosion in which the entire surface of the metal is bruised to the identical degree of corrosion when subjected to a corrosive environment. For uniform corrosion, the corrosive environment must have the same access to all parts of the metals surface, and the metal itself must be metallurgically and compositionally uniform. These conditions are not normally prevalent in the majority of operating equipment, and some degree of nonuniformity is tolerated within the definition of uniform corrosion.

b) Galvanic/Bimetallic Corrosion

This is the form of corrosion often occurs in marine environment. The fact that most structures and devices are made of more than one kind of metal, this diversity of materials is common and frequently overlooked in corrosion prevention activities.

The corrosion occurs when two dissimilar metals come in contact with each other in the presence of an electrolyte to form an electrical couple, know as galvanic couple (anode and cathode). The electrolyte may be moisture mainly water or high atmospheric humidity. When a galvanic couple forms, one of the metals in the couple becomes the anode and corrodes faster than it would all by itself, while the other becomes the cathode and corrodes slower than it would alone.

The prediction of which metal to be corroded in the galvanic couple can be made through the ranking of metal in the Galvanic Series. The metal on the upper portion of the series would corrode preferably by releasing electrons than the metal on the lower portion of the series.

The two major factors affecting the severity of galvanic corrosion are the voltage difference between the two metals on the Galvanic Series, and the size of the exposed area of cathodic metal relative to that of the anodic metal.

Galvanic cells could also be formed within the material due to difference in composition and stress level, notwithstanding that this classification of galvanic cell is very uncommon.

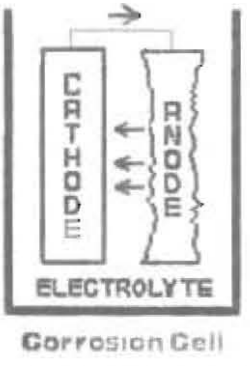

Figure 2.2: Basic Galvanic Couple [http://www.cathodicprotection.com/cpintro.htm]

c) Pitting Corrosion

Pitting is a form of localized attack that produces holes or pits in a metal. [Smith] It is because of the inhomogeneities in metal made up from inclusions, coring and distorted zones. These inhomogeities will produce potential differences in which pits will initiate.

The propagation of a pit is believed to involve the dissolution of the metal in the pit while maintaining a high degree of acidity at the bottom of the pit. The pits will continue to aggravate until the perforation of metal. If perforation occurs, it will cause destruction to the engineering structures. [Smith]

d) Cavitation Corrosion

High velocity flow and pressure changes in liquid such as encountered by pump impeller and ship propeller will give rise to cavitation. Cavitation is defined as rapid vaporizing of liquid whenever the local pressure is less or equal to the vapor pressure. The evolving bubble on the surface would subsequently collapse and burst due to the high stresses of the vibrating motion, removing particles from the component's surface. Eventually, deep pits, depressions and pockmarks are formed and caused damage to the structure.

e) Crevice Corrosion

It is a general term including accelerated attack at the junction of two metals exposed to a corrosive environment. This type of electrochemical corrosion occurs in crevices and under shielded surfaces where stagnant liquid exist.

Accelerated attack can occur because of a differential in oxygen concentration. Oxygen has relatively easy access to the outside of the joint, which is cathodic. The metal in the joint being deprived of oxygen is relatively anodic. The deposit of insoluble corrosion product around the anodic center tends to more completely exclude any presence of oxygen, resulting in a low oxygen concentration are and thus increased electrical potential. Eventually, a pit is formed in the center.

Crevice corrosion is very important in engineering because it occurs under gaskets, rivets, and bolts, which may have a huge impact on the structure. The best way to avoid crevice corrosion is to eliminate crevice utterly by changing the material used in the design.

f) Intergranular Corrosion

Intergranular corrosion is localized attack when a potential difference between the grain boundaries and the adjacent alloys. The situation arises as a result of the differences in concentration of alloying elements between the grain boundaries and the adjacent materials. This type of corrosion usually takes place when precipitation of phase from a solid solution occurs. Grain boundaries are often the preferred sites for the precipitation and segregation processes observed in many alloys. [Trethewey and Chamberlain] Since precipitation usually occurs faster at grain boundaries, the material in the vicinity of the grain boundary becomes depleted of the dissolved element, creating difference in potential and the grain boundary will corrode. As time goes by, the intergranular corrosion will cause the loss of strength of the alloy and even the disintegration at the grain boundaries.

g) Fretting Corrosion

Fretting is common type of surface damage which occurs at the interface between materials under load subjected to vibration and slip. The oxidation and corrosion product is continually torn loose by the wearing action. As a result, oxide particles are accumulated on the surface act as an abrasive between the rubbing surface.

h) Microbiologically Induced Corrosion

When metal is exposed to untreated aqueous substances containing living microbial organisms, these organisms have a tendency to form colonies on the metal surface, especially in the areas containing gross surface irregularities such as welded joints leading to corrosive condition.

Desulfovibro and *Desulfotomaculum* are sulphate-reducing bacteria (SRB), which are the far most troublesome micro-organisms associated with corrosion of iron and steel. They are anaerobic bacteria capable of reducing sulphate ions to sulphide ions. They are found in virtually all-industrial aqueous processes and can a lot of damage to the industry. [Trethewey and Chamberlain]

i) Stress-Corrosion Cracking

Stress-corrosion cracking can be intergranular or transgranular cracking of metal caused by the combined effect of the conjoint action of a static tensile stress and specific corrosion environment. During stress-corrosion cracking, the metal's surface is usually attacked very little while highly localized cracks propagate through the metal section. Depending on the corrosive medium and on the structure of the base

metals, stress-corrosion cracking involves stresses that may be significantly below the yield strength of the material.

2.1.3 Elements Of Corrosion Reaction

They are many theories, which are used to explain about the process of corrosion. Apart from unusual types of corrosion such as bacterial or direct chemical attack, the electrochemical theory fits the facts most closely regarding the corrosion in metal. In an electrochemical reaction of corrosion, the following four conditions must exists at the same time for corrosion to take effect:

1. The anode or anodic area where the corrosion occur when the current leaves the metal to enter the electrolyte in the form of ions.
2. The cathode or anodic area where little or no corrosion occur and where the current, caused by the flow of positively charged ions through the electrolyte, is maintained by being neutralized at the cathode with electrons from the external connection to the anode.
3. An electrolyte in which the anode and cathode is immersed into. An electrolyte is any solution that contains ions. Pure water is an example of electrolyte, containing hydrogen ions (H^+) and hydroxyl ions (OH^-) in equal amount.

4. A conducting path for the return of the current from the cathode back to the anode.

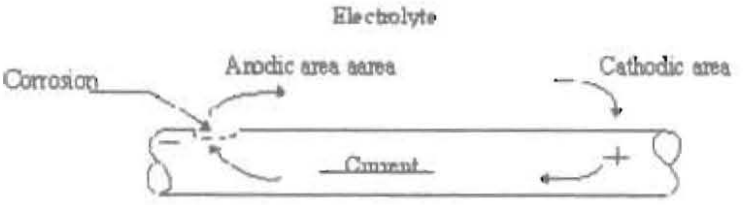

Figure 2.3: Corrosion Cell In Steel Pipe [http://www.cps.com.au]

2.1.4 Basic Corrosion Cell

A basic corrosion cell requires a voltage or electromotive force to exist between the anode and cathode immersed in an electrolyte environment before there is the possibility a corrosive current flow taking place. The greater the eletromotive force of the metals, the stronger the current. The conductivity of the electrolyte environment and that of the electrical return path are the other factors, which will determine the magnitude of the corrosive current.

When the cell is completed, the anode is corroded by loss of electrons from electrically neutral metal atoms in the solid state to form discrete ions. The cathode, however sustain little or no corrosion during the process. The ions from the anode will react with other species at the interface to form insoluble solid corrosion which usually accrue on the metal surface. Other products such as hydrogen, chlorine gas and oxygen may also be formed.